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Energy functional retrofitting of historic residential buildings: the case study of the historic center of Perugia

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Abstract

The built heritage is characterized by an average low energy performance, but it is often excluded from studies and retrofit scenarios. In Italy, as in Europe, the building sector is the most energy consuming and pollutant. Italy accounts for 40% of the European historical heritage, which is not concerned by the building performance legislation. The description and the analysis of the residential building stock is the object of this work, presenting an overview of the historical typologies built since the XII century. The case study is the entire historic center of Perugia. A major step was to choose a qualitative methodology that combined together four main approaches in order to categorize the all ancient buildings in the old town: (1) historical documentation and municipal documental information (2) in situ investigation; (3) surveys to the occupants; and (4) infrared thermography. The first approach allowed to identify five typological archetypes while the subsequent steps allowed to define sub-typologies relatively to energy performance. The knowledge of the characters of the old manufactured buildings is crucial to improve the energy efficiency of the built heritage.

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Keywords: *Historic buildings; Energy efficiency; Energy saving; Strategy; Preservation*

1. Introduction

The building sector shows a large potential for saving energy. Buildings use around the 40% of total EU energy consumption and generate almost 36% of greenhouse gases in Europe [1, 2].

Since we must find a way that can help to decarbonize the environment through the minimization of the energy consumption, the great challenge seems to be the retrofit of the existing buildings. In Italy approximately 70% of the buildings (data based on ISTAT Census 2001) were built before the release in

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1976 of the first law establishing limits for the energy consumption in building sector [3] [4]. Moreover, around 85% of this stock consists of buildings continuously occupied, indicating the large potential in energy conservation for residential sector.

In order to improve the building's efficiency, the European Commission launched the first Directive on building Energy Performance - 2002/91/EC - shortly named as EPBD [5] and transposed and implemented in Italy by the Legislative Decree 192/2005 [6]. Since this first Directive took greater account of the new buildings, which are a minor part compared to the built stock, it has been launched the second Directive - 2010/31/UE - [7] implemented in Italy one year later with the Law 90/2013 [8]. The provisions of this law do not apply to all buildings that fall under the regulations of Part Two and Article 136, paragraph 1, letters b) and c) of Legislative Decree 22 January 2004 n. 42 of the Code of cultural heritage and landscape (Article 3, paragraph 3) [9]. This means all Italians historical centers are in derogation from law. In some cases in order to protect the aesthetic-historical value of the worth constructions technological measures for retrofitting are not applied or when applied they might be inappropriate and undermine the cultural heritage preservation.

In response to this conflict, the present study aims to develop a methodology which classify the historic stock constructed until the second World War, and therefore mainly pre-industrial. The methodology aims to estimate the energy performance of buildings in order to simulate suitable refurbishment scenarios in a future study. The research had two different target: the primary objective was to carry out an overview on general and recurrent typological archetypes at district level. The second target is focused on the energy categorization of the archetypes in sub-typologies that already received energy refurbishment measures in the recent years.

It will be shown which are the single best technologies eligible for the energy efficiency of ancient buildings without compromising their historical, artistic, architectural value, with the aim of simulating suitable - even if basic - recovery scenarios.

Many studies have debated the method for evaluating the energy performance of a built settlement and considered strategies with the aim to improve the energy efficiency of heritage building stocks. Fracastoro and Serraino [10] focused their work on Italian realty and proposed an analytical procedure for the "Statistical Distribution of Residential Buildings" (E-SDOB), applicable at regional or national scale. Hrabovszky-Horvatha et al. [11] based their bottom-up methodology in order to simplify building type upon a non-real building documentation.

Fabbri et. al [12] have integrated GIS with geometrical census data and with a cadastre of a numbered certification reported on the SACE DATABASE, in order to perform study and simulation on the whole tissue of the historic city center of Ferrara.

Far fewer are the studies dedicated to address the issue of the retrofit in built heritage. This is due to a mismatch. In fact, all buildings that have turned 50 are classified as historic [13]. Not all the historical buildings, however, have an aesthetic, historical or architectural prominence: they are classified as historical only due to the factor's age.

This paper basically differs from those aforementioned for because only pre-industrial buildings were considered and was used a mix of top – down and bottom – up methodology. General real data of old urban tissue detected from the technical Department of municipality were summed up in five main typologies. The survey revealed that the total number of residential buildings in the historic center of Perugia is 1,889. In the following section the analysis of architectonic typologies of the historic city center of Perugia, concerning the preliminary phase about data retrieval, the energy inventory's executive phase [14] of the entire building stock will be discussed.

2. Methodology

In Fig. 1 and Fig. 2.a, the strategy to make organic both the collection and the analysis of heterogeneous data is presented. There have been two major phases: the preliminary and the executive. In the central part of the diagram, in purple, the data's collection is shown. On the left, the actors involved are presented in orange and on the right in blue are mainly the tools used and the tasks performed.

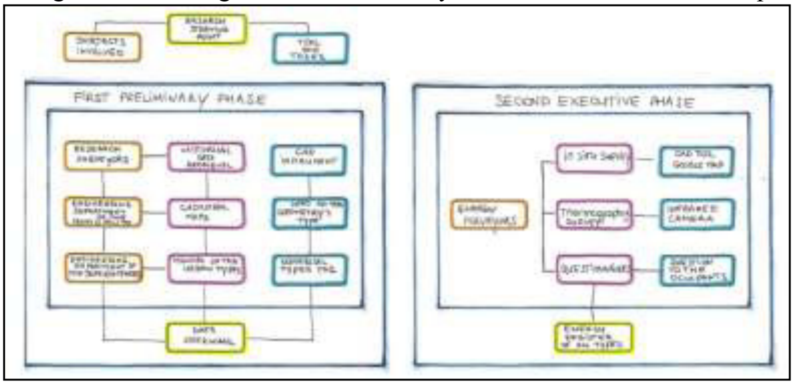

Fig. 1. Methodology chart

3. Case study presentation – Perugia old town

The case study is based on the entire historic center of the city of Perugia, a city of medium - small size located in Central Italy, with a population of about 9,000 residents. To note that was not considered the municipal boundary of the city, larger and more extensive, but only the area "A" i. e. the historic center as defined by Italian legislation (Article 2, paragraph A) [15] The limit of the historical city center is shown in Fig. 2.b. Zone "A" consists almost entirely of buildings built before 1919 and maximum until 1945.

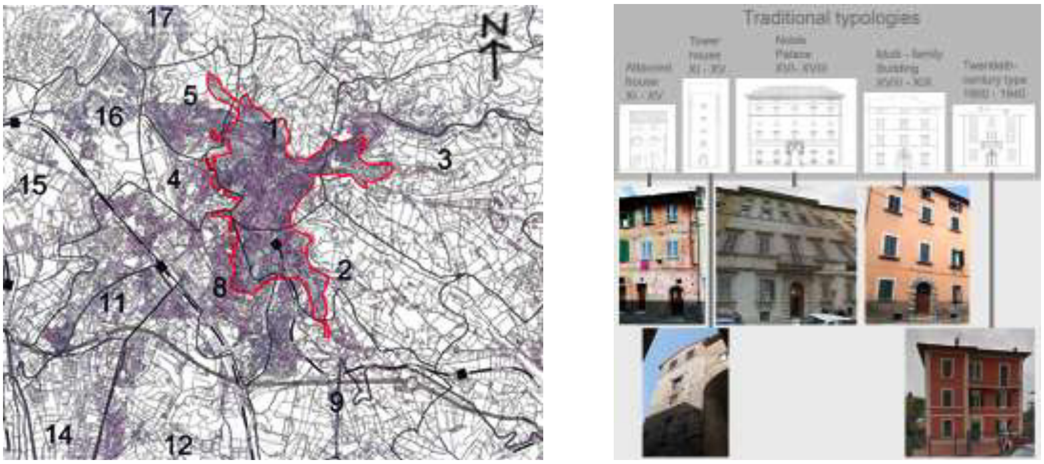

Fig. 2. (a)Edge of the old town; (b) Breakdown of Perugia city center in five historical typologies

4. Analysis of the architectural typologies of Perugia' s old town, preliminary phase: historic data and maps retrieval

For the reduction of energy consumption is it imperative to do retrofit actions on existing substance. Generally, this reduction also implies the increase of the indoor winter comfort conditions and the economic value of the properties and to lower energy bills. To promote the enhancement of the architectural heritage through energy refurbishment, the first essential step is a deep knowledge of the building and its physical context from the environmental and the historical point of view. A different methodology was adopted, compared from other proposals in the literature, allowing to standardize both the data collection proceeded from various technical office departments and the data from literature sources useful for recovering the history of urban evolution. Using real data and real geometries, the difficulties that comes either from the lack of reliability of some statistical data or the uncertainties due to the estimation of volumes and surfaces were surpassed. The information collected, obtained through the surveys carried out in 1999 by the municipal technical departments and land registry technical departments prepared for Perugia urban plan - P.R.G. [16], were very useful. Two of the maps were particularly interesting for the research: the one that identifies the residential sector and the one that indicates the typologies and intended uses (convent, church, hotel, residence etc.). To determine the five types shown in Fig. 3 and their total number (i.e. 1,889), data of the residential tissue and data found in the "Abacus of traditional types recurring in the urban regional context" were used [17]. The abacus provides the geometric characteristics of the types, measured with CAD tool and compared with the map plan provided by the Municipality of Perugia. On the map a layer to identify only the residential urban tissue was initially created, then layers to achieve the five types target were added. Finally, all the residential buildings were numbered and an alphabetical code for each type was created. In order to check the actual and precise position and the orientation of dwellings, it has been very useful the Google Map tool.

5. Second executive phase

In order to establish an energetic inventory to improve the energy performance of the building, a study was performed (consisting of three main phases listed below) throughout the residential urban tissue of the old town. The investigation revealed that the most common Perugia's acropolis building type is the medieval terraced house: 1268 units. Then follow multi-family buildings built between the seventeenth and nineteenth century (283 units); current types built between 1900 and 1940 (279 units); the noble palaces of the XVI and XVII century (49 units) and finally the medieval towers (11 units) almost completely disappeared, because of papal supremacy that destroyed them. The study assumes exclusively the analysis of the building envelope and therefore the measures considered for the improvement of performance are simplified but also feasible from the legal point of view. The measures considered are: replacement of windows and glass; internal or external wall insulation; roof insulation.

5.1. In-situ check

The in-situ check is the main part of analysis, because it allows investigators to observe the general condition prevailing in the entire built heritage of the historic center of Perugia. A simple camera can help. Energy investigators can easily understand if retrofits (replacement of windows, new roof, external insulation) were made or not.

5.2. Thermography

The thermal images of the building stock were carried out only on the vertical exterior opaque walls. Thermographic camera is a useful tool to see if the walls and roof are insulated or not, if there are heat losses and where these losses are major. In Fig.3 it can be observed that the greater heat dispersion take place in correspondence of the window frame and below it, where a heater is installed.

5.3. Questionnaires

The energy auditors delivered by hand questionnaires to the occupants of the historic center of Perugia. Three hundred questionnaires were delivered and were created collection points where return the completed ones. About half of the questionnaires were returned. Questions were related to energy efficiency measures taken or not, to improve the energy efficiency of the building envelope. It was also made a survey on the average annual cost of energy bills. The questionnaire proved to be a very useful tool to gather information and make estimates percentages on energy measures adopted.

6. Discussion and results

The main results of the above described analysis are displayed in Table 1. In table 1 is shown the sample size for each building typology and also the number of objects analyzed with the different approaches previously cited. Overall, it has been analyzed the 18% of Perugia old town buildings. The most present typology (i.e. terraced house) appear to be the less analyzed, both for numerical questions (very large sample) and for the uselessness of covering a high percentage, given the homogeneity of the architectural and construction features.

Table 1. – Objects analyzed per typology and approach.

Typologies	Total number of houses	Total number of analyzed houses	Questionnaires numbers	Thermographies number	Surveys number
A - Terraced house	1268	153	38	47	68
B - Tower house	11	9	2	2	5
C - Noble palace	49	21	9	5	7
D - Multi-family building	283	97	23	21	53
E - Actual typology	278	61	33	3	25
Total	1889	341	105	78	158

In Fig.4 the results of the analysis are shown. On average, the majority of the different buildings typologies analyzed does not suffered interventions. The most frequent intervention is the replacement of windows and window frames. Latter intervention is frequently combined with additional roof insulation. The other combinations for retrofit interventions are much less common and statistically cover less than 7% of the sample analyzed, regardless of typologies. Fixtures retrofit is more prevalent either for the average lifespan or the reduced impact of the intervention.

Many other studies show similar situations in the historical building. More than half of the buildings do not suffer any intervention: the potential energy saving is therefore to be exploited. It is to be noted that the terraced houses, the most numerous, are also those on which less intervention were carried out.

A large part of this buildings typology is usually rented to students or foreigners. The owners have no interest in making energy efficiency improvements of the old dwellings as they are not directly involved. This is a very important barrier to energy efficiency.

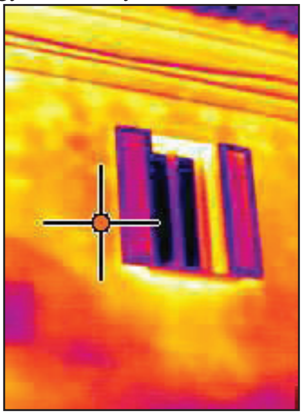

Fig. 3. Façade thermographic image of a terraced house

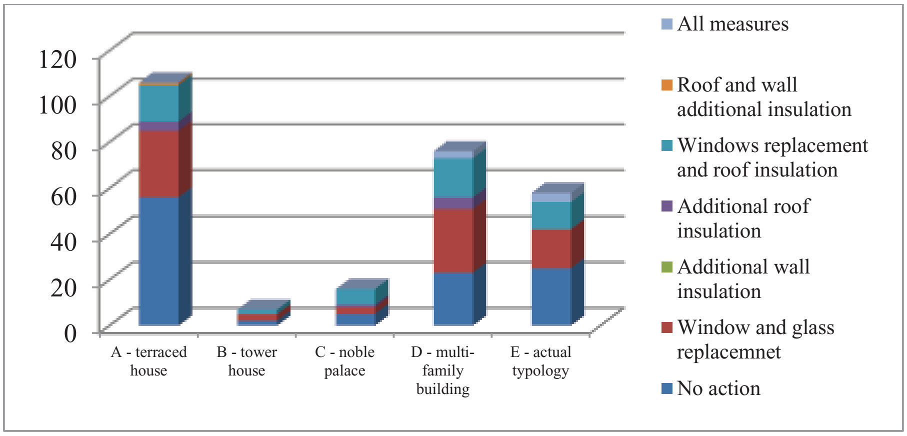

Fig. 4. Refurbishment strategy per building typology.

7. Conclusions and future developments

The outcomes presented here are a part of a long and extensive three-year research work. An in depth study was conducted about the pre-industrial buildings of the old town of Perugia and also concerning buildings from 1900 until 1940. Pre-industrial constructions were not subject to a codified construction process and to regular urban planning. The building materials were found on site, depending on the financial availability. It has been developed a simple methodology based on the retrieval of cadastral data, that led to the development of an energy inventory of the whole historic building stock in the old town of Perugia. The methodology is also applicable to all major towns in Umbria. In fact, to identify the typologies, was adopted the abacus of recurring and traditional regional types. Many other cities in north-central Italy have terraced houses, tower houses, multi-family buildings and noble palace. Potentially, the methodology is also applicable to all cities having such kind of typologies. Three were the main results of this work: a) a tool which is the starting point for the calculation of the potential savings at municipal level; b) the methodology is potentially replicable for all those municipalities having got historical building stock; c) the tool is useful for local governments that has to deal with policies for energy saving. In a future work will be quantitatively evaluated the potential energy savings of the supervised stock, by applying technological measures for retrofit also considering the point of view of the costs and benefits.

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Biography

Martina Giombini Architect, Ph.D. student in Energy Engineering at University of Perugia. Her research interest concerns building energy efficiency with focus on retroffiting of existing buildings and insulation materials.